# The development and validation of a framework for teaching software engineering through startup practice in higher education

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# The development and validation of a framework for teaching software engineering through startup practice in higher education

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***Abstract*—Context: Approaches to teaching software engineering are becoming more interdisciplinary and team-centered, similar to a startup practice context. Therefore, educators must have an adequate framework for supporting software engineering teaching through startup practice. However, only a meager set of existing frameworks introduce startup practice to teach software engineering. Aim: Our study aims to develop and validate a framework for teaching software engineering through startup practice in higher education. Method: We developed a framework for introducing startup practices in software engineering education. We first identified the framework domains (course teaching and design perspectives, course theoretical lens, and course design and interaction practices) based on a previous literature review pinpointing lean software startups as part of software engineering education research. We further identified dimensions for each domain based on investigations in both our software engineering experience-based course and growth phase startup context. Finally, we validated the framework using a Delphi method. Results: We found that the perception of the framework dimensions was positive among the experts who, on average, rated 14 out of 19 dimensions as highly important (approximately 75%) and the rest (25%) as of average importance. From the current results, we are able to deduce that our proposed framework can provide realistic learning expectations for SE students but also for other disciplines that can relate to software engineering. Contribution: The study's outcomes contribute to developing and validating a framework for teaching software engineering through startup practice in higher education. Our framework lays a foundation for educators and researchers by successfully combining experience-based software engineering courses with lean software startup industry practices. Furthermore, our framework contributes to students acquiring adequate professional skills to address societal challenges with a mindset focused on increased innovation and startup formation.**

***Keywords — software engineering education, framework, startup practice***

## I. INTRODUCTION

Approaches to teaching software engineering (SE) are becoming more interdisciplinary and team-centered, similar to a startup practice context. Therefore, educators must have an adequate framework for supporting software engineering teaching through startup practice. Experience-based learning enables students to develop skills based on their experiences [1] and learning experientially [2] on multi- and interdisciplinary teams in innovative courses [3,4]. We find several studies [1–6] which combine inter- and multi-disciplinary teams for realistic product creation through startup practices in an academic setting. Software-intensive courses focused on minimum viable product (MVP) creation are also common [7–10]; we made previous efforts to propose models that integrate startup concepts within software-intensive experience-based courses [11-15]. However, to the best of our knowledge, there is no framework supporting student skills and startup-formation motivations incorporating external activities (i.e., an Innovation Bootcamp) in software-intensive experience-based courses.

Our study aims to develop and validate a framework for teaching software engineering through startup practice in higher education. We have identified the framework domains based on a previous literature review [16] pinpointing lean software startups as part of software engineering education research. To develop our framework, we adopted design-based research [17], a dual-purpose methodology that aims to bridge theory and practice in education. It blends empirical educational research with the theory-driven design of learning environments to improve educational practices through iterative analysis, design, development, and implementation, with active collaboration between researchers and practitioners in real-world settings. Design-based research relates to educational action research and design science, but it emphasizes educational improvement [18]. Each iteration seeks to improve the previous artifact based on collected empirical evidence. In the framework development process, 44 students (student cohorts 1 and 2) answered questionnaires over two academic years. We also conducted four individual interviews (student cohort 1), four focus group interviews (student cohort 2), and six individual interviews with stakeholders participating over the two years of the study.

We validated the framework using a Delphi method. In a Delphi procedure, a panel of experts rates a questionnaire on different rounds until consensus or stability in panel members' responses is reached [19]. Tigelaar et al. [20] introduces the development and validation of a framework of teaching competencies in higher education. In our case, we involved educational experts and researchers in the software startup field (N=15), asking a set of questions for each domain in two consecutive rounds.

During framework development, we focused primarily on students' skills and startup formation motivations. Respectively, we found that perceptions of challenges regarding soft and project management skills declined, while perceptions of challenges regarding technical skills did not vary during the course. Students' motivation to engage in startup formation increased after the close collaboration with external stakeholders and their first MVP development. We first carried out a pilot in which two experts gave their judgment on the Delphi questionnaire during framework validation. Second, we conducted two rounds of questionnaires with education experts and researchers. The response rate was 86%. However, the experts and researchers successfully answered all 20 items for all the domains. The shift in ratings was minimal, thus reaching stable results, confirming the value of the four frameworks' dimensions, activities, and corresponding actions.

The rest of the paper is structured as follows. Section II presents related work. Section III describes our designed course settings. We present our study's design and methodology in Section IV. Section V presents the results and key findings. Section VI discusses the findings. Finally, Section VII concludes the study and identifies opportunities for future work.

## II. Related Work

### A. Lean Software Startup Education Trend

Lean software startup is moderately notable in the software engineering education (SEE) context as part of education for millennials [21], having indicators as a newly emerging strategy. Previous studies report that this approach provides a realistic education setting [22,23]. Specifically, Buffardi et al. [24] claim a contribution to new tech startup formation while experimenting with software engineering and entrepreneurship students. Often, collaborations arise between industry and education, leading to startup formation [25].

### B. Innovation Bootcamps in SE Courses

Kolb introduced experience-based learning as a tool for students to utilize their background competencies to develop their skills [1,2]. Researchers have made numerous efforts to introduce experience-based learning to higher education. Common approaches are based on Innovation Bootcamps, which involve intensive, three-to-four-day, hands-on, experiential-learning events. During the Bootcamps, students utilize design-thinking concepts, determine problems, and outline solutions for challenges [26]. Consolidating Innovation Bootcamps practices in software-intensive, experience-based courses deserves researchers' attention because of its benefits for students' technical, soft, and project-management skills, primarily through close interaction with external stakeholders.

Sidhu et al. [27] conducted a four-day intensive Bootcamp on innovation and entrepreneurship to influence students' mindsets toward innovation. The authors utilized the BII open-project concept to measure whether students could learn entrepreneurial behaviors. To determine their results, the authors used pre- and post-tests questionnaires before and after the Innovation Bootcamp.

Moshirpour et al. [28] designed a Bootcamp-based course focused on technical and programming skills to reinforce programming skills for non-programmers; they reported no soft or project-management skills. The authors surveyed at the end to assess student learning outcomes and satisfaction.

Similarly, Hickey and Salas [29] introduced Bootcamps as a new model for learning web and mobile development and software entrepreneurship. The authors conducted a longitudinal study focused on activities similar to incubators and accelerators boosted by educational content. Based on Pappas [8], efforts have been made in an experience-based course toward introducing a hackathon as an external activity within an experience-based course in software engineering.

Nandi and Mandernach [30], as well as Sakhumuzi and Emmanuel [31], have used hackathons as an instrument of informal and collaborative learning in software engineering project-based courses. However, we found no other studies that incorporated bootcamps in software-intensive, experience-based courses.

### C. Educational Frameworks

Tigelaar et al. [20] introduces the development and validation of a framework of teaching competencies in higher education. The authors use a Delphi method to validate the developed framework. The Delphi method was used to find out whether educational experts could reach a consensus on important teaching competencies. The authors conclude that a new framework of teaching competencies should be appropriate for more student-focused approaches to teaching.

Ciancarini et al. [32] validated the theoretical model of cooperative thinking to train teams of students to manage software engineering problems. The authors claim that they are advancing a new computer science competence, the aim of which is to support cooperative problem-solving of technical contents to address complex software engineering problems. To validate the proposed educational framework, the authors used structural equation modeling with partial least squares. The authors conclude that from a pedagogical perspective, cooperative thinking practices and educational curricula need to be outlined in more depth.

Sedelmaier et al. [33] presented SECAT as a multi-perspective framework to evaluate software engineering education by assessing students' competencies. SECAT builds upon an approach from vocational education. According to the authors, SECAT considers team achievements as well as individual ones, integrates multiple perspectives from various groups of stakeholders, and pays attention to the outcome of a task as well as the process that was used to solve the task. SECAT also covers technical as well as non-technical competencies in an integrated framework.

## III. Course Settings

We designed our master's degree Experts in Teamwork course based on Kolb's experiential-learning approach [1]. We expected students to identify innovative solutions that they can tackle using SE. Every project should attempt to achieve the sustainable development goals (SDGs) as defined by the United Nations [34]. In the past two years, we updated the course by introducing Innovation Bootcamp activities.

*1) The cohorts.* The cohorts over two academic years comprised teams of five to seven students with different study backgrounds, including SE. The teams' main characteristic was their multi- and inter-disciplinary composition. Each team was required to apply group process theory [35] when coping with challenges and improving team dynamics.

*2) Course enrollment.* We provided a course website, publicly available during both academic years. A total of 21 and 23 students participated in the first and second years of the course, respectively. Table I reports the cohort demographics for each academic year.

TABLE I. COURSE DEMOGRAPHICS

| | *Cohort 1 (2019)* | | *Cohort 2 (2020)* | |
|---|---|---|---|---|
| | N# | Percentage | N# | Percentage |
| **Gender** | | | | |
| Male | 11 | 52% | 15 | 65% |
| Female | 10 | 48% | 8 | 35% |
| **Age** | | | | |
| 18–25 | 9 | 43% | 11 | 48% |
| 26–30 | 11 | 52% | 8 | 35% |
| 31–40 | 1 | 5% | 4 | 17% |
| **Academic Discipline** | | | | |
| Software, Computer, Electronic Engineering | 7 | 33% | 12 | 52% |
| Other (Social Sciences, Psychology, Geology) | 14 | 67% | 11 | 48% |

## IV. METHODOLOGY

Our framework development has undergone the three major steps presented in Figure 1. We first identified the framework domains based on a systematic literature review pinpointing lean software startups as part of SEE research. Second, we used design-based research to propose a model unfolding the underlying dimensions for each domain and sustained by empirical evidence collected from two consecutive iterations in our experience-based SE course at the Norwegian University of Science and Technology. Finally, we developed our framework based on gathered evidence and validated the start of our validation process by collecting opinions from the most renowned experts in the field. The research methodology work is primarily based on the triangulation of quantitative and qualitative methods [35] that explore different researchable facts through various investigation types.

### A. ***Step 1:*** *Systematic review of SE Trends in SEE.*

We conducted a systematic mapping study about teaching major software engineering trends in project courses. In our study we classified 126 papers based on their investigated software engineering trends, specifically software engineering processes and practices, teaching approaches, and the evolution of software engineering trends over time [16]. The study allowed us to position lean software startup as part of the SE Trends in SEE.

### B. ***Step 2:*** *Model Development Methodology.*

To propose our model and thus identify dimensions for the domains under analysis, we adopted design-based research [37,38], a dual-purpose methodology that bridges theory and practice in education and blends empirical educational research with the theory-driven design of learning environments to improve educational practices through iterative analysis, design, development, and implementation, with active collaboration among researchers and practitioners in real-world settings. Each iteration seeks to improve the previous artifact based on collected evidence (Figure 2).

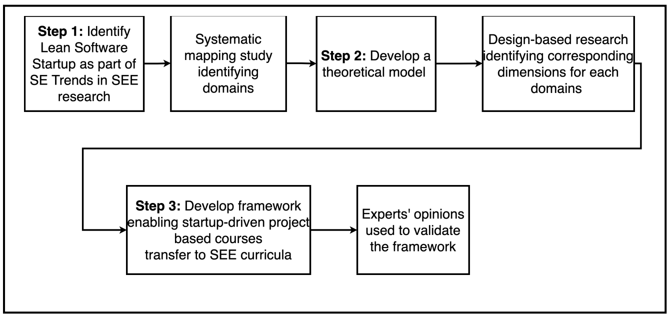



Fig. 1. Methodology design.

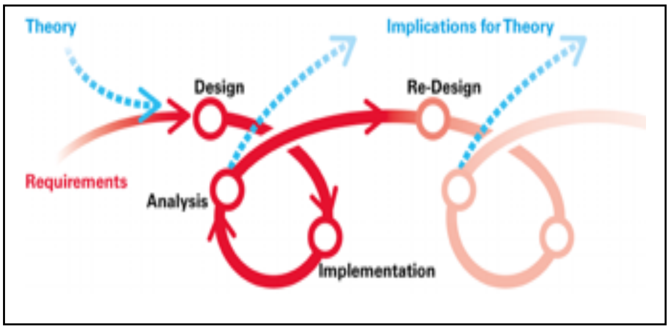



Fig. 2. Design-based research approach. Source adapted from [39].

We gathered the initial data through questionnaires and the supplementary data through interviews in both years. We classified our research into the following phases: (1) research design and preliminary investigation (quantitative approach: questionnaires), and (2) exhaustive understanding and data analysis (qualitative approach: semi-structured interviews).

### C. *Framework Development and Validation Methodology*

*1) Framework Development.* The framework development is based on domains and dimensions conceptualized during our previous and current research. We have identified the framework *domains* based on a previous literature review pinpointing lean software startups as part of software engineering education research. We used the empirical evidence collected during our model development to identify the corresponding *dimensions* for each domain. It is noteworthy to mention that we have supported our proposed educational framework based on empirical evidence we gathered from the growth phase startups [16–20]. This makes the framework a strong fit for bridging the industry and academic contexts.

*2) Subjects.* As an initial step to our framework validation, we decided to apply the Delphi method [18]. For the Delphi study, renowned educational experts were selected who work in higher education. These experts were selected because they are involved in teaching lean startup or have a long track record in startup education. All these experts have ideas on which teaching competencies are required in SE project-based courses and lean startup. The experts also represent several institutions from different countries. Furthermore, the experts that were selected have at least five years' experience in higher education, with some having over twenty years of experience. The process of identifying the experts started with a presentation at a software startup research network. The presentation served as an initial step for brainstorming ideas for developing the framework and identifying the experts that were willing to participate in the study. We have to admit that with such strict criteria, a varied and knowledgeable panel was composed, but the number of experts in the field of interest for our study could not exceed 12 experts. These experts received an invitation via email to participate in the Delphi study.

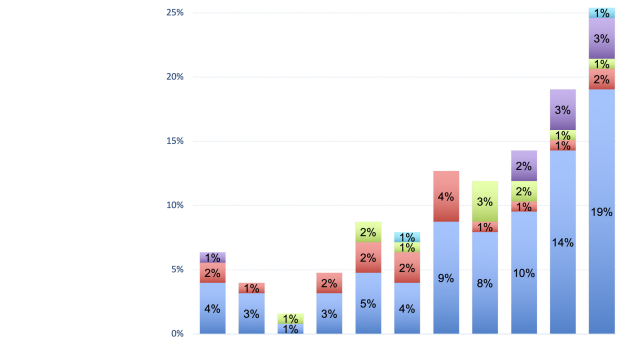
*3) Procedure.* We performed our study during the spring of 2021 (from March until April). First, a pilot was carried out in which two experts gave their judgment on the Delphi questionnaire. On the basis of the findings from this pilot, the wording of some items was made unambiguous to prevent misinterpretations. All ten out of the twelve chosen educational experts who accepted to partake in our Delphi study received the round one questionnaire (tinyurl.com/framework-delphi). They rated 19 items corresponding to 19 different questions on a Likert scale, with one aditional option allowing them not to rate any answer they did not feel comfortable answering. In the second round, we asked the experts to fill in the questionnaire, which included a summary of the ratings of the panel member for each item in round one and the mean and standard deviation of all participants' responses in round one. We asked the panel members to return a rerated questionnaire if they wanted to reconsider their initial answers after viewing the other experts' opinions.

*4) Data analysis.* It is common in a Delphi study to confront panelists with the results after each round until consensus or results' stability is reached. In our case, we defined stability or convergence as occurring when there was insignificant or no additional shifting of experts' panel responses from one round to the other. We chose as a criterion of stability for mean scores a shift of 20 percent or less after successive rounds, which is a shift of less than one on a scale of one to five. Consensus was defined as agreement between panelists on rating a particular item within a specific round. We defined 75% as a minimum percentage of agreement on any particular item. For calculating the consensus, scores 1 and 2 were computed as (totally) unimportant, 3 as average, and 4 and 5 as (very) important. This implies that in this study, an item is viewed as (very) important when 75 percent of the educational experts rated this item with a score of 4 or 5.

## V. Results

### A. Framework Development

*1) Domains established from systematic review.* We provide an overview of the evolution of SE trends in SEE in Figure 3, which is taken from a more extensive study on SEE Trends [16]. We find from the study that agile software development was the primary SE trend investigated in SEE. Two other emerging trends in 2013 and 2016 are GSE and lean software startups, respectively.




| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Agile Software Development | 5 | 4 | 1 | 4 | 6 | 5 | 11 | 10 | 12 | 18 | 24 |
| Software Implementation, Usability and Value | 2 | 1 | 0 | 2 | 3 | 3 | 5 | 1 | 1 | 1 | 2 |
| Global Software Engineering | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 4 | 2 | 1 | 1 |
| Lean Software Startup | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 4 |
| System of Systems | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

Fig. 3. Focus evolution from SEE research on SE Trends over time [16].

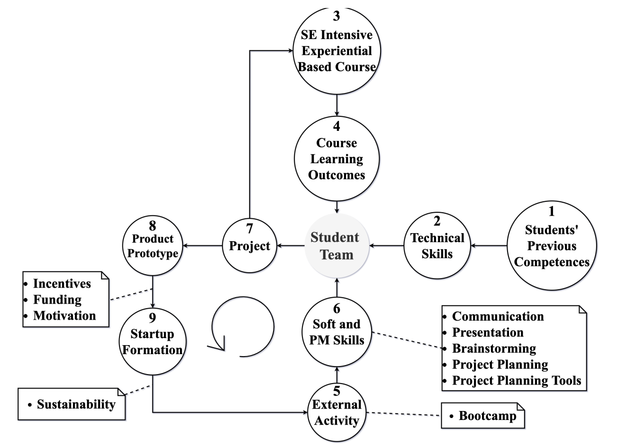



Fig. 4. Our proposed EiT course startup-driven model [15].

We notice an increased interest in the lean software startup SE trend since 2016. We identify important dimensions of lean startup in SE education related to project-based learning, often combined with experience-based learning, lean, and agile practices and tools, and multi- and interdisciplinary contexts. We also observe a plethora of interactions among students, educators, mentors, practitioners, and researchers within the lean software startup trend.

*2) Model Dimensions.* Our framework relies on dimensions from our previously proposed student team-centered model [15] (Figure 4). We observe from the model that both technical and soft skills are critical to a successful student team. Students' prior competencies are the primary source of technical skills (**nodes 1** and **2**); team diversity makes teaching these unrealistic, but soft skills can be taught effectively. An experience-based course builds good team dynamics with teaching assistants' and course leaders' active participation (**node 3**), while learning outcomes are defined from the beginning, so we know more precisely what the course's team benefits are (**node 4**).

We still argue that students must endeavor to solve realistic problems based on external stakeholders' needs.

TABLE II. FRAMEWORK DOMAINS, DIMENSIONS, AND CONTEXT

| Domains | Dimensions | Corresponding Question | Context |
|---|---|---|---|
| Course Teaching and Design Perspectives | Soft, technical, and project management skills | Q1 | Experience-based courses designed around Lean Startup |
| | Realistic Projects | Q2 | |
| | Innovation mindset | Q3 | |
| | Multi- and inter-disciplinary teams | Q4 | |
| | Funding opportunities | Q5 | |
| | External industry and government stakeholders | Q6 | Innovation Bootcamp external activity |
| | Students and stakeholders addressing sustainable development goals | Q7 | |
| Course Theoretical Lens | Kolb group dynamics theory | Q8 | Startup and Bootcamp theory in multi/interdisciplinary SE experience-based courses |
| | Software startup formation practices and motivations | Q9 | |
| | Innovation Bootcamp theories | Q10 | |
| Course Design and Interaction Practices | Learner-Learner interaction | Q11 | Course and Innovation Bootcamp focusing on Lean Startup |
| | Learner - Instructor/Facilitator interaction | Q12 | |
| | Learner-Content interaction | Q13 | |
| | Learner-External Stakeholder interaction | Q14 | |
| Tools | Lean business model canvas | Q15 | Course and Innovation Bootcamp focusing on Lean Startup |
| | Scrum framework tools (Trello, Jira, Burndowns etc.) | Q16 | |
| | Lean Persona and Kanban boards | Q17 | |
| | Landing Page or App Builders | Q18 | |
| | Customer Journeys | Q19 | |

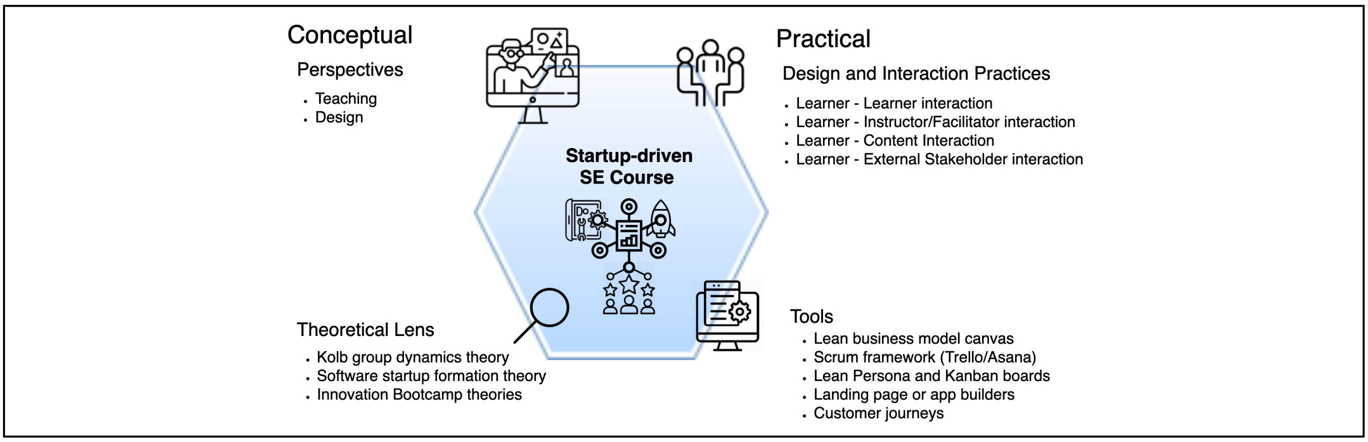



Fig 5. Experience-based SE course framework.

Based on the results, exposure to external activity (e.g., the Innovation Bootcamp) probed variations in students' soft and project-management skills. We observed little impact on students' technical skills by the Innovation Bootcamp. Specifically, external activity is key to developing realistic soft and project-management skills (**nodes 5** and **6**). The team is supposed to deliver a worthwhile project (**node 7**) that is part of the course evaluation (**node 3**) or developed further into a functional product prototype (**node 8**). We observe a greater interest in startup formation after the Innovation Bootcamp (**node 9**). Startup-formation motivations can be amplified by (1) incentives, (2) funding, and (3) personal motivations. The course leader should (1) incentivize startup formation within the course, such as networking with external stakeholders, and (2) provide applications to local funding opportunities.

*3) Framework Domains and Dimensions.* Our framework relies on dimensions from our previously proposed student team-centered model [15], our growth-phase startup research [40–42], and opinions gathered from renowned experts in the startup education field (Table 2). Meanwhile, Figure 5 provides a graphical represenation of our proposed framework characterized by its domains, with corresponding dimensions categorized in conceptual and practical areas. We categorized the course domains into four distinct parts, each

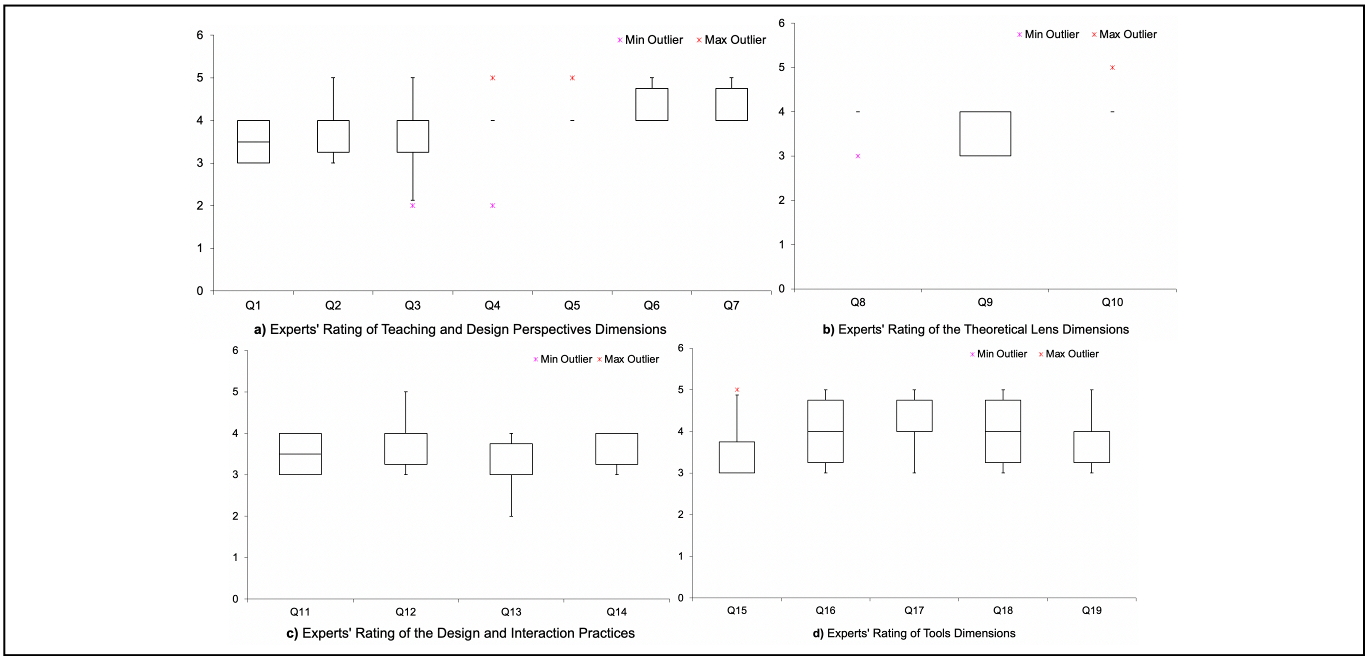



Fig. 6. Experts' ratings of dimensions for each domain (Reference to Questions (Q) can be found at tinyurl.com/framework-delphi).

with its corresponding dimensions. The domains are a consequence of studies on lean software startup for education [20–24] identified in our initial literature review [16]. We later adopted similar approaches aggregated with our unique course model design relying on particular dimensions. Namely, course teaching and design perspectives are tightly connected to students' technical, soft, and project management skills, which have been widely discussed in previous literature. We designed our model around experience-based courses relying on inter- and multidisciplinary teams addressing sustainable development goals.

However, contrary to the previous approaches found in the literature, we introduced external activities, such as Innovation Bootcamp, as a practice widely adopted in the startup context. The theoretical lens domain that our framework builds upon is based on experience-based learning theory as a subset of project-based learning, growth phase software startup practices, and Innovation Bootcamp theories. Combining the three domains allows the framework to provide students with adequate knowledge of SE practices.

The framework promotes a strong interaction among students (learner-learner), students and instructors (learner-instructor), and student-industry/government expert (learner-external stakeholder interaction). The interaction of the student with the course material is somewhat weak (learner-content) since the expectations are on students relying on their previous competencies to develop the final project. The tools proposed by the framework vary, from those in lean and agile project development to those with some flavor of tools from Innovation Bootcamp activities.

## B. Framework Validation Results

Ten out of twelve (83%) experts agreed to participate in the Delphi study. After round one, seven completed questionnaires out of ten were returned (70%). The means and standard deviations of each item were computed. In round 2, we shared the results from the round 1 questionnaires and asked the participants if they agreed with the result summary or if they wanted to fill in answers a second time in case they changed their opinion. Since none of the experts returned different values on the current results, we concluded that a consensus was reached and that the results obtained were stable without having the need to introduce a consecutive round.

We calculated the mean and variance of the obtained answers in the form of box plots (Figure 6). Student skills had a mean of 3.5 and were thus considered the average when related to lean startup practices. However, we observed that questions Q2 to Q7, which were related to the first domain dimensions—such as items related to realistic projects, student innovation mindset, multi- and inter-disciplinary teams, funding opportunities, participation of external industry and government stakeholders, and students and stakeholders addressing sustainable development goals—were rated as very important, with a mean score of 4. The last two dimensions, which were related to the participation of external stakeholders and students addressing sustainable development goals alongside external stakeholders, were only rated with values of 4 and 5.

Questions 8 to 10, which were related to the theoretical lens dimension, also presented an average of 4 and were thus deemed very important by the experts.

Questions related to the course design and interaction practices reflected different variations. Question 11, which was related to learner-learner interaction, had a mean value of 3.5, which is considered a little above average.

Meanwhile, the question related to learner-instructor interaction (Q12) had a mean value of 4 and was thus considered to be very important. The learner-content interaction (Q13) had a mean value of 3 and was thus considered of average importance. Finally, the learner-external stakeholder (Q14) interaction had again an average of 4 and was thus considered very important by the experts.

The first question (Q15) in the tool domain related to the lean business canvas model has a mean of 3 and was thus considered average. Meanwhile, the rest of the questions (Q16–Q19) related to different tools of agile and lean all had a rate of 4 and were thus considered very important by the experts.

**Key Findings**

1. The experts rated the students' technical, soft, and project management skills related to lean software startup with an average value.
2. The most highly rated dimensions are those related to the participation of external stakeholders and the addressing of sustainable development goals alongside students via an Innovation Bootcamp external activity to the course.
3. All the theoretical dimensions introduced by the framework are deemed very important by the experts.
4. We observed a mixed appreciation of the interactions, where learner-learner and learner-content are the least valued, whereas learner-instructor and learner-external stakeholder were the most valued by the experts.
5. Overall, we found no mean values below the average of 3 among all the experts' ratings.
6. Two dimensions (student innovation mindset and learner-content interaction) received ratings below average (2) by some of the experts.

## VI. Discussion

### A. Startup-driven SE course

The intersection in Figure 7 between experience-based learning, growth phase startup theory, and the Innovation Bootcamp allows us to propose a framework leading to students learning SE via startup formation.

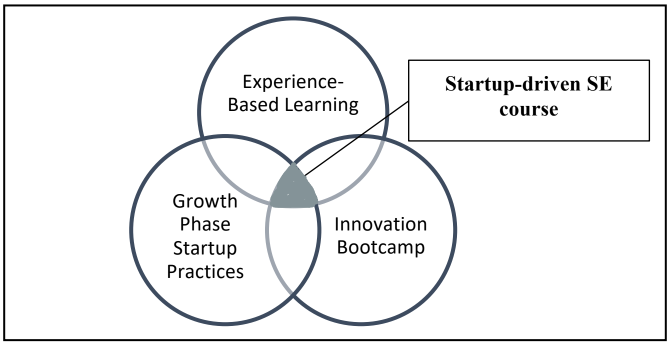



Fig. 7. Intersection between experience-based learning, growth phase startup practices and Innovation Bootcamp promting for a Startup-driven SE course concept.

We thus coin the term *startup-driven software engineering course* by defining it as "*an experience-based course paradigm, set of growth phase startup practices and tools under the project-based learning theoretical umbrella with the objective of enabling student teams to create startups within a course context, supported by Innovation Bootcamp external activity, while further expanding students' prior knowledge and competencies in software engineering.*"

Hypothesizing based on these values is not an option due to the small sample, which would not provide any significance from the statistical analysis [43]. We further discuss our study limitations in section VI.D. The qualitative results reported in Section 5B provide initial insights into the experts' perceptions about our proposed framework domains and their corresponding dimensions.

We have orchestrated the framework development over the past three years of research with the goal of gathering experts' opinions to validate our findings. The instrument we used (Delphi) gives us initial insights into our framework domains' and dimensions' worthiness.

We find that student skills are not truly considered highly important by the experts, which aligns with the part of our findings and model where technical skills are not truly influenced by the course or the Innovation Bootcamp. However, the participation of external stakeholders facilitated by the Innovation Bootcamp received high ratings from the experts. The same applies to the challenges proposed by the stakeholders addressing sustainable development goals. These dimensions might be considered very important since they enact the possibility for the students to address realistic real-world challenges, which also makes it a primary keyword for our framework.

Deeming the learner-interaction dimension not very relevant is not at all surprising, since the students are still expected to utilize previous knowledge and competences, sometimes not strictly related to software engineering, in order to develop their projects. Thus, the content provided for the course is somewhat limited. However, we find that two of the results related to learner-learner and learner-instructor interactions did not completely fit our expectations. More precisely, we expected that the former would be considered highly relevant in the face of creating a new startup.

Nevertheless, our previously gathered evidence [11-15] is also aligned with the experts' ratings since students were not very keen on creating startups with existing team members only. However, for the latter, we expected it to be less significant since the instructor would be playing a facilitating/mentoring role, which is nevertheless key to student team success. We were somewhat surprised by the fact that the student innovation mindset did not also receive higher ratings.

Overall, the perception about the framework dimensions was positively perceived by the experts who, on average, rated 14 out of 19 dimensions as highly important (approximately 75%) and the rest (25%) as of average importance. From the current results, we can deduce that our proposed framework can provide realistic learning expectations for SE students but also for other disciplines that can relate to software engineering. We have not been able to analyze and compare how other disciplines (e.g., entrepreneurship) can benefit from our framework; however, we can only argue that the primary benefit is related to them working with realistic projects while addressing realistic challenges.

### B. How can educators, researchers, and practitioners use our findings?

Our study contributes to educators by helping them: (1) adopt a realistic approach to teaching SE by promoting innovation traits for the students, (2) introduce external activities such as Innovation Bootcamp in the course, which would help interaction with stakeholders and projects having real-world relevance, and (3) let students take an active role in transforming educational projects into startups that benefit academia, industry, and society.

Researchers can: (1) conduct further investigations on how Innovation Bootcamps or similar activities (e.g., hackathons and innovation workshops) can impact similar project-based courses, and (2) augment the dimensions to investigate (e.g., end product quality, product growth, startup establishment, intellectual property rights) while utilizing our current findings.

Finally, practitioners (e.g., external stakeholders) should: (1) understand the value of participating in Innovation Bootcamp activities, (2) utilize students' inputs and ideas to bring value to the challenges they face and understand the possibility of having students create startups to tackle those challenges, and (3) be collaborative in partnering up with students towards startup formation opportunities during and after the course setting.

### C. *Threats to Validity and Limitations*

We use recommendations from Maxwell [43] to address validity threats related to our study: (1) **Content validity.** In our study, we analyze generally accepted dimensions by the research community in SE literature. Moreover, we consider studies that rely on project-based learning and potentially overlapping with common SE practices. Relying on focus-group interviews helped us obtain a deeper understanding of the phenomenon under investigation; (2) **External validity.** We commonly relate external validity to the sample size used and the limited context under consideration. We upheld this validity by choosing a sample of renowned experts. We have to admit that ours is a pilot study based on a limited number of participants. We recommend a larger sample size to be able to generalize the results. In the future, we intend to lessen this threat to validity by recruiting a larger sample of experts for follow-up interviews; (3) **Construct validity.** Due to the small sample size, we require additional experimentation to assess our quantitative data's construct validity. However, based on the data collected so far, the validation results are reasonably consistent compared to previous evidence.

It should be acknowledged that the Delphi technique, as adjusted in this study, also has some limitations. First, we can mention some comments related to the questionnaire. Many dimensions had a mean of 4, which could indicate that experts deemed them important. However, this could also mean that it was difficult for the experts to discriminate between the dimensions.

Moreover, it was difficult to do justice to all the definitions and theories related to our study. However, we have tried to coin a definition for our proposed framework that provides the core description of our developed course. The results indicate that in most domains, the items that are broadly defined (e.g., stakeholder participation in the course and Innovation Bootcamp activity) are rated as more important than the more detailed dimensions (e.g., lean business canvas model). Second, we can mention some limitations concerning the selection of the experts.

Although several experts were selected, it was difficult to make a meaningful distinction in the kind of experts that were selected. At least we kept some criteria in check as a filter in selecting competent experts. Another challenge was that experts represent several institutions with different course policy-making and teaching cultures. Third, there is no evidence yet that the results of this Delphi method are reliable. We do not know if we would have obtained the same results based on a distinct panel of experts selected using equivalent criteria. Therefore, further validation of the framework with another panel using equivalent criteria might be needed. Another option is to interview and get further insights from the already selected experts.

## VII. Conclusions and Future Work

We developed our framework based on empirical evidence gathered from our two-year research in developing a multi- and inter-disciplinary experience-based course around Innovation Bootcamp activity and growth phase startup practice we gathered from our research. The students had the chance to interact with external stakeholders in developing realistic projects addressing SDGs and real-life societal problems with SE instruments. We conducted an extensive literature review to identify our framework's domain and applied design-based research to map every domain to corresponding dimensions. Finally, we validated our framework based on the Delphi method.

Based on the initial results provided by the experts, we conclude that our framework provides a realistic setting for learning SE. Evidence is still needed that compares our proposed framework with other existing frameworks evaluating students' competencies in the field of SE. Nevertheless, the results so far are promising and indicate an overall acceptance by the experts. Finally, as the validation process is not yet completed, the developed framework should be field-tested.

Therefore, our plans consist of mitigating the present study limitations by conducting a similar study with a larger sample, including practitioners as part of the panel and not just educators. We also intend to pilot the developed framework in other sibling project-based SE courses.

We encourage other educators and researchers to consider our framework when developing their SE project-based courses and consider how students can have a more active role via Innovation Bootcamp activities and acquire more realistic skills via startup formation.

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